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Modeling of Soil Loss and Identification of Erosion Hot Spot Areas Using RUSLE Integrated with GIS for Appropriate Conservation Practices in Muga Watershed, Highlands of Ethiopia

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Abstract
Over cultivation, deforestation and free grazing are major factors facilitating soil erosion. Nowadays; in lower parts of Muga watershed soil erosion become as a continuous environmental problem. In this study an attempt has been made to modeling soil loss and identify the most erosion sensitive areas by using Revised Universal Soil Loss Equation integrated with GIS and remote sensing techniques for planning appropriate conservation measures in Muga watershed. The annual soil loss amount was estimated by using the Revised Universal Soil Loss Equation (RUSLE). Digital Elevation Model, digital soil map, thirty years rainfall records of six stations, and land cover data (Landsat images) were used to develop RUSLE soil loss variables. The annual soil loss rate from the catchment were estimated by integrating RUSLE parameters using raster calculator tool. The annual soil loss rate varies between 0.02 ton/ha/yr and 41.789 ton/ha/yr. The total annual soil loss in the watershed was 59751.41 tones, of these, 12806.15 tons were lost from 371.19 km^2, 26562.44 tons from 214.30 km^2, 15300.94 tons from 50.52 km^2, 4059.05 tons from 4.61 km^2, and 1022.83 tons from 0.37 km^2 of land per year. The rate of soil eroion was high in the lower part of the watershed. Slope gradient and length factor was the main factor for soil erosion increment followed by Support Practice (P) factor. As result of soil erosion cross tabulation; steep slopes, Rendzic leptosols and dominantly cultivated areas were detected as very severe erosivity. Therefore, the lower parts of the study needs to undertake effective soil and water conservation practices.
Keywords: Soil loss, RUSLE, GIS, Remote sensing, Moga Watershed, Erosion hot spot areas
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1. Introduction

Soil erosion by runoff is the process of detaching and transporting of soil particles by flowing water to downstream areas (Kunta, 2009). Soil erosion has an adverse effect for developing countries like Ethiopa, since agriculture is the main source of income and food, which is dependent on the soil fertility (Hurni, 1993). Soil erosion has been considered as the most serious land problem, due to it's on-site and off-site effects on the food security and the economy of the country (Hurni, 1993; Sutcliff, 1993; Lulseged and Vlek, 2005).

Soil erosion is mostly caused by accelerated soil erosion which is principally favored by human activities. Soil erosion has a profound impacts on crop production, reservoir sedimentation, and downstream flooding (Hurni et al., (2015), Haregeweyn et al., (2015b)); while as economic costs and ecosystem services has been well documented by Hurni et al., (2015) and Haregeweyn et al., (2015a,b, 2016) respectively. As compared to flat areas, soil erosion at the steep areas has high adverse effects (Taye et al., (2013) and Descheemaeker et al., (2006). But for overall rates of total soil loss, at regional or national scales, very few estimates are available according to Sonneveld et al., (2011). Due to soil erosion, in Ethiopian highlands 23400 million metric tons soil is lost per year (FAO, 1984; Hurni, 1993).

In developing countries like Ethiopia unsuitable land cultivation, overgrazing and deforestation have accelerated soil erosion rates per hectare of land (Reusing et al., 2000; Tamene and Vlek, 2008; Zemenu and Amare, 2014). The expansion of agricultural practices had been increasing the amount of soil erosion in the Ethiopian high lands (Aster, 2004; Zemenu and Amare, 2014). In Muga watershed between 1986 and 2009; the cultivated land had been increased from 40.01% to 76.47% (Demeke and Andualem, 2018).

Amount of soil loss is affected by different factors like overgrazing and cultivation, population pressure, deforestation, erosive rainfall and rugged terrain features (EHRS, 1984). Identifying highly soil erodible areas is important to mitigate the influences of soil degradation and to assist the conservation and rehabilitation practices for basins. In this regard, integrating the USLE model and GIS technique for estimating annual soil loss contributes a lot to alleviate the existing problem by identifying soil degradation areas.

Therefore, this study is conducted to address the following objectives: (1) to estimate the amount of soil loss rate, (2) to generate erosion severity and erosion hazard maps and (3) to identify erosion hotspot areas for appropriate conservation measures.

2. Methodology

2.1 Description of the Study Area

Muga watershed is found in Amhara region between 10°6'30''N to 10°43'30''N latitude and 37°49'00''E to 38°16'30''E longitude and it has an area of 641 km^2 (Figure 1). Muga River originates from Choke Mountain at an elevation of 4092 m.a.s.l and flows to Abbay River. The agro-climatic zones of the study area are attributed by wet/moist dega (temperate like climate-highlands) and kola (hot and arid type) zones (NMSA, 2001). The study area characterized as a wet season from June to September and dry season from October to May. The mean annual precipitation of the study area is found 1445 mm, and the minimum and maximum temperature are 5 °C and 25 °C respectively. Soil groups which are found in the study area are Eutric Vertisols (56.68%), Chromic Luvisols (28.55%), Humic Nitosols (5.42%) and Rendizic Leptosols (9.35%). The topography of study area ranges between 1199 m.a.s.l and 4092 m.a.s.l (Demeke and Andualem, 2018).

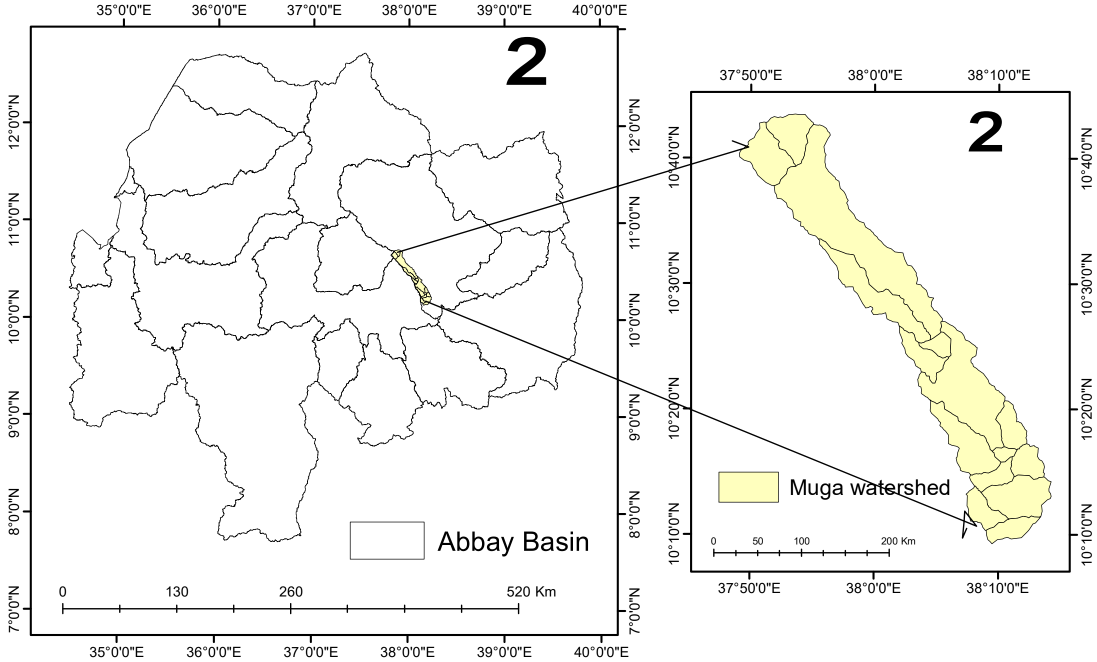

Figure 1. Location of study area

2.2 Sources and Techniques of Data Collection

For this study, both secondary and primary data sources were used. By using Global Positioning System (GPS) instrument, both field survey and observation was conducted for actual primary data collection. The land use land cover map of the study area were developed by using supervised image classification and Ground Control Points (GCPs) for validating the accuracy of image classification. Secondary data were collected from different organizations like meteorological data (1986-2015) from National Meteorology Agency (NMA); soil and Digital Elevation Model (20*20 m) from Ministry of Water, Irrigation and Electricity (MoWIE), land use/cover map of 2013 from Ethiopian mapping agency. The slope length–steepness (LS) factor was derived from digital elevation model.

2.3 Soil Loss Estimation

In this study, Revised Universal Soil Loss Equation (RUSLE) integrated with Remote sensing and GIS technique was used to estimate the mean annual soil loss. RUSLE is expressed as equation 1:

$$A \text{ (tons/ha/year)} = R*K*LS*C*P \text{--} (1)$$

Where A is the annual soil loss (tons/ha/year); R is the rainfall erosivity factor (MJ mm/ha//h/yr); K is the soil erodibility factor [tons/ha/year]; LS is the slope length-steepness factor (dimensionless); C is the cover and management factor (dimensionless, between 0 and 1); and P is the support practice factor (dimensionless, ranges from zero to one).

To calculate the amount of soil loss rate in the study area, all the erosion factors (R, K, LS, C, and P) were determined based on the previous recommendations to Ethiopian highlands (Hurni, 1985a). The spatial distribution of soil loss was developed by integrating the erosion influencing factors in Arc GIS the raster calculator geo-processing tool.

2.4 Estimation of RUSLE Parameters

Rainfall erosivity (R) factor: quantifies the effect of rainfall impact and reflects the amount of runoff likely to be associated with precipitation events (Xu *et al., 2008).*

The model adopted by Hurni (1985) for Ethiopian condition was based on the available mean annual rainfall data (P) where:

R = - 8. 1 2 + (0. 5 6 2 x P) -- (2)

R= rainfall erosivity P= mean annual rainfall (mm)

R-factor were estimated from the 30 years (1986 to 2015) mean annual rainfall data of six stations (Abay sheleko, Debre Markos, Mota, Bichena, Yetmen and Yetnora) (Table 1).

Table 1 Mean annual rainfall of rain gauge stations around the study area

No.	Station Name	Location		Elevation (mm)	Mean annual rainfall (mm) (1986-2015)
		Longitude (mm)	Latitude (mm)		
1	Abay Sheleko	407638.2	1117924	1823	1296.25
2	Debre Markos	361926.9	1141626	2446	1360.69
3	Mota	378760.2	1224277	2417	1196.88
4	Yetmen	406605.5	1141810	2418	1322.97
5	Yetnora	402309.3	1132533	2420	1215.51
6	Bichena	412769.5	1154619	2532	1389.43

Source: National Meteorology Agency, 2016 (computed)

Soil Erodibility (K) Factor: The original vector format soil map was converted into raster format. The grid format was then reclassified based on K-value for each soil class in Arc GIS 10.1 using reclassification geoprocessing tools. Provided that the reclassification of the raster soil map was done according to the major soil types given by Hurni (1985a) and Hellden (1987) (Table 2).

Table 2 Major soil types with their corresponding K-value

No.	Major soil type	K-value
1	Chromic luvisols	0.158
2	Eutric Vertisols	0.132
3	Humic Nitisols	0.128
4	Rendzic Leptosols	0.127

Source: Reconnaissance Physical Land Evaluation in Ethiopia (FAO, 1989)

Slope Length -Steepness (LS) Factor

The topographic LS factor (Slope length and slope steepness) was determined using equation 3 (Moore and Burch, 1986a and b; Engel, 2005) with the help of raster calculator:

LS={[Flow Accumulation (with set threshold limits)*[Cell size]/22.13}$^{0.4}$ {Sin [Slope]/0.0896}$^{1.3}$--- (3)

Where LS is slope steepness- slope length factor; flow accumulation and slope derived from conditioned digital elevation model.

Support Practice (P) Factor: Erosion control practice factor (P-factor) is the ratio of soil loss with a specific support practice to the corresponding loss with upslope and downslope cultivation (Wischmeier and Smith, 1978). The P-value for the this study were assigned based on land use class regardless of the slope class they have (Table 3).

Table 3 Major land uses with their corresponding P-value

No.	Major land use/cover	P-value
1	Afro-alpine	0.8
2	Dominantly cultivated	0.95
3	Moderately cultivated	0.95
4	Urban	1.0

Source: Wischmeier and Smith (1978)

Cover and Management(C) Factor

The cover and management (C) factor represent the ratio of soil loss from land with specific vegetation to the corresponding soil loss from continuous fallow (Wischmeier and Smith, 1978; Morgan, 2005). C-factor for this study area has been determined from land use of the area (Table 4).

Table 4 Major land uses with their corresponding C-value

No.	Major land use/cover	Source	C-value
1	Afro-alpine	BCEOM, 1998	0.01
2	Dominantly cultivated	Hurni,1985	0.15
3	Moderately cultivated	Hurni,1985	0.1
4	Urban	BCEOM, 1998	0.05

The RUSLE model was simulated by GIS and remote sensing techniques to identify erosion hot spot areas (Figure 2).

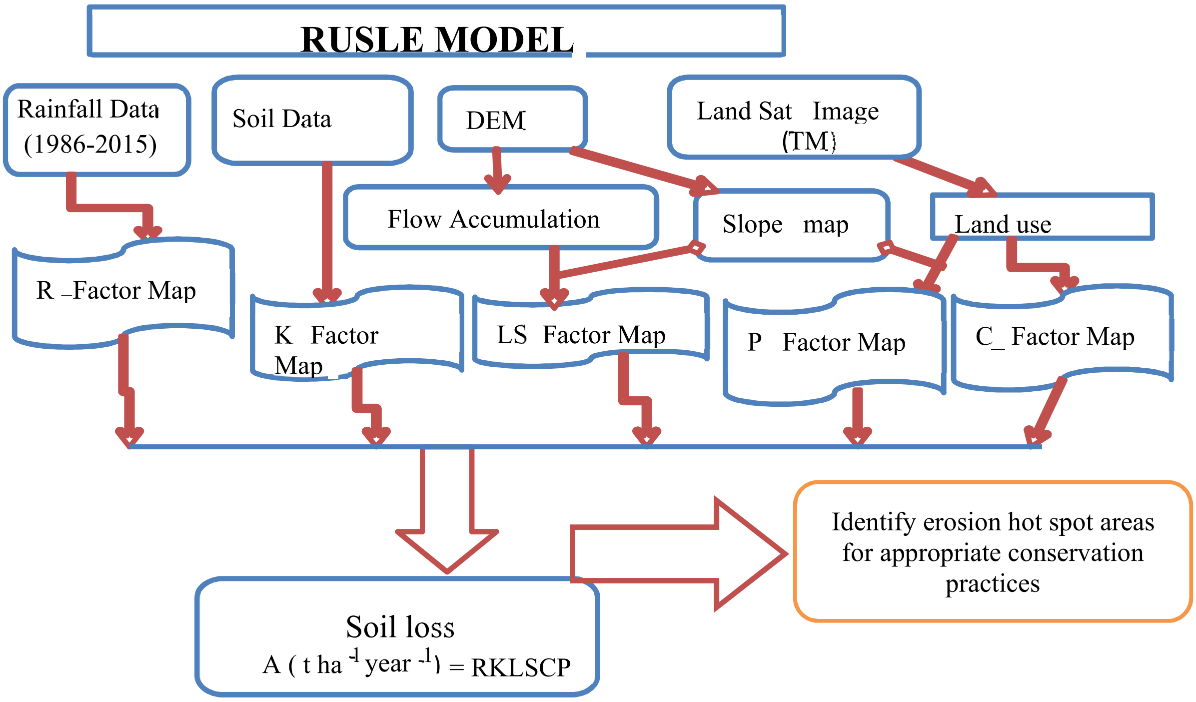

Figure 2. Conceptual Framework of Soil Loss Analysis by RUSLE Model

3. Result and Discussion

3.1 Estimation of Soil Loss and identification of hotspot areas

In this study, RUSLE equation was integrated with Arc GIS 10.1 technique to conduct cell by cell calculation of mean annual soil loss rate (ton/ha/year) and to identify high erosion hot spot areas in Muga Watershed. Raster map of each RUSLE parameters was derived from different data sources and discussed as follows.

Rain Fall Erosivity(R) Factor

The values of R-factor (Table 5) in Muga watershed ranges from 664.53 (Mota station) to 772.74 (Bichena station). The R- factor values for each station was assigned with color (Figure 3a).

Table 5 R-factor values of rainfall stations

No.	Station Name	Elevation (mm)	Mean annual rainfall (mm)	R-Factor
1	Debre Markos	2446	1360.69	756.59
2	Mota	2417	1196.88	664.53
3	Yetmen	2418	1322.97	735.39
4	Yetnora	2420	1215.51	675
5	Bichena	2532	1389.43	772.74

Soil Erodibility (K) Factor

The K-value for each major soil class (Figure 3b) was assigned with special reference to their color (Hurni, 1985). Chromic Luvisols have high k-value (0.158) which are highly affected by erosion. Humic Nitisols and Rendzic Leptosols have low soil erodibility factor with k-value of 0.128 and 0.127 respectively. These soils are less susceptible to detachment and erosion. An area of 182.99 km^2 was highly erodible while 59.92 km^2 was less erodible to soil erosion (Table 6).

Table 6 K-values and area coverage of major soils

No.	Major Soil type	K-value	Area (km^2)	Area (%)
1	Chromic Luvisols	0.158	182.99	28.55
2	Eutric Vertisols	0.132	363.23	56.68
3	Humic Nitisols	0.128	34.73	5.42
4	Rendzic Leptosols	0.127	59.92	9.35

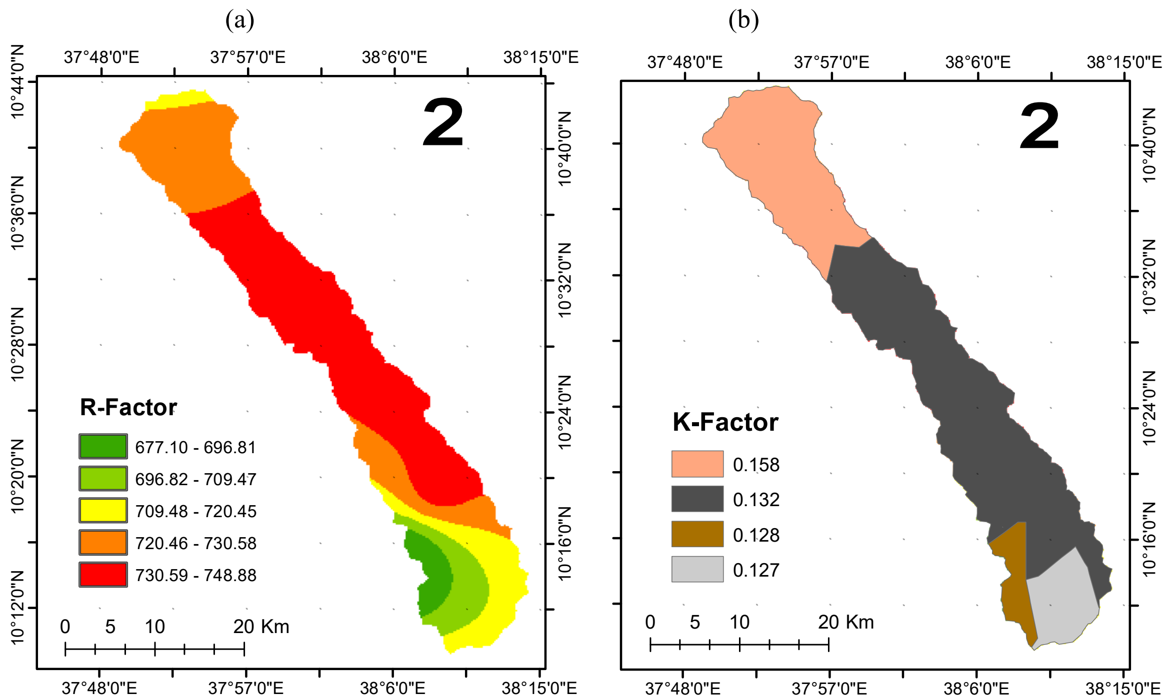

Figure 3. (a) R-factor and (b) K-factor

Slope Length and Steepness (LS) factor

LS-factor was computed using equation (3) suggested by Moore and Bruch (1985); Mitasova and Mitas (1999); and Simms *et al*., (2003). According to the analysis, the LS factors of the watershed were found in the range of 0.275 to 21.786. Upstream and downstream parts of the watershed had the highest value of LS and middle part of the watershed had the lowest value of LS which was distributed in gently flat to undulating terrain. This indicated that the upstream and downstream parts of the study area are highly sensitive to soil erosion (Figure 4a).

Table 7 Slope length factor (LS) values

No.	LS-value	Area (km^2)	Area (%)
1	0.275-1.118	367.87	57.91
2	1.119-2.214	212.38	33.43
3	2.215-3.733	50.07	7.88
4	3.734-6.264	4.57	0.72
5	6.265-21.786	0.37	0.06

Support Practice (P) Factor

The values of P-factor were found between 0.8 and 1.0 (Table 8). The highest P-value was found in the upstream part of the study area, while the smallest values were observed in the downstream and middle parts of the watershed (Figure 4b).

Table 8 P-Factor values of Muga Watershed

No.	Land use/cover	P-value	Area (km^2)	Area (%)
1	Afro-alpine	0.8	150.04	23.39
2	Dominantly cultivated	0.95	222.01	34.61
3	Moderately cultivated	0.95	268.53	41.87
4	Urban	1.0	0.81	0.13

Cover and Management (C) Factor

As shown in table 9, the value of C-factor was found between 0.01 and 0.15. The dominantly cultivated land has a large value of c-factor (0.15) which is highly vulnerable to erosion. Next to dominantly cultivated land, moderately cultivated land (0.1) is moderately vulnerable to soil erosion. Afro-alpine and urban having the c-factor values of 0.01 and 0.05 respectively are less vulnerable to erosion (Figure 4c).

Table 9: Cover and management (C) values

No.	Land use/cover	C-value	Area (km^2)	Area (%)
1	Afro-alpine	0.01	150.04	23.39
2	Dominantly cultivated	0.05	222.01	34.61
3	Moderately cultivated	0.1	268.53	41.87
4	Urban	0.05	0.81	0.13

(a) (b) (c)

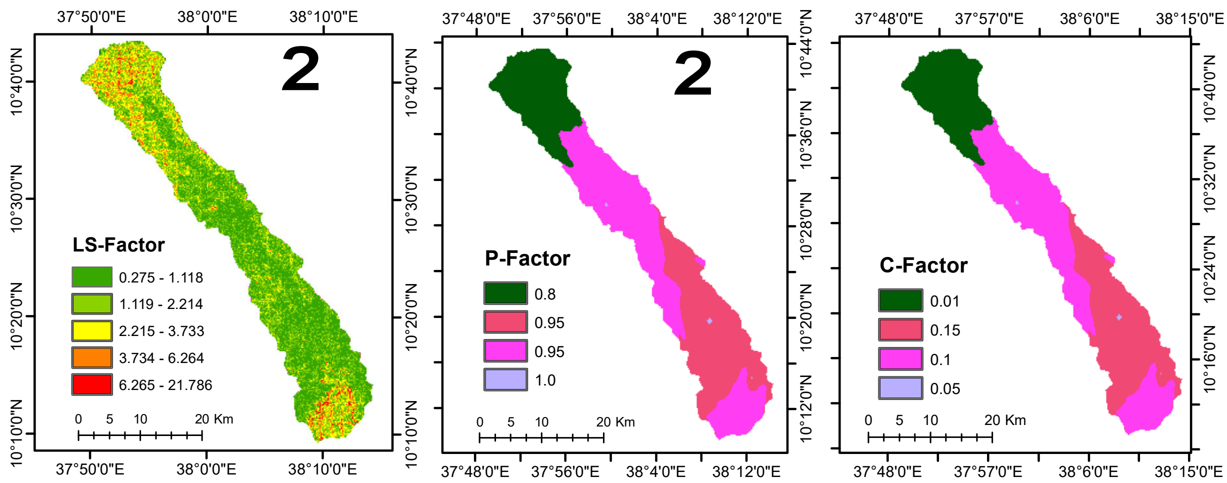

Figure 4. a) LS-factor, b) P-factor c) C-factor

3.2 Estimation of Soil Loss

RUSLE is an empirically based model that has the ability to predict long term average annual rate of soil erosion on slopes using data on rainfall pattern, soil type, and topography, conservation, and management practices. Potential annual soil loss was estimated from the product of factors (R, K, LS, C, and P) for the Muga watershed ranges from 0.02 – 41.489 ton/ha/yr. The estimated level of soil loss rate was classified into five classes as shown in figure 5. The classified soil loss map showed that 99.22% of the total area falls under the tolerable rate followed by 0.78% of the total area comes under critical soil.

Table 10 showed that there are 12806.15 tons of soil loss from 371.19 km^2 area, 26562.44 tons soil loss from 214.30 km^2 area, 15300.94 tons soil loss from 50.52 km^2 area, 4059.05 tons soil loss from 4.61 km^2 area, 1022.83 tons soil loss from 0.37 km^2 per year. Results revealed that severe to extreme severe erosion risk areas found in the downstream parts of the watershed due to the presence of steep lands, over cultivation, high rainfall and overgrazing. In the middle part of the watershed, it was observed the low erosion damage area.

Table 10 Erosion intensity class and distribution in the study area

No.	Soil loss rate (ton/ha/yr.)	Severity class	Area (km^2)	Area (%)	Annual soil loss (ton)	Soil loss (%)
1	0.02-0.67	Very low	371.19	57.91	12806.15	21.43
2	0.671-1.808	Low	214.30	33.43	26562.44	44.45
3	1.809-4.248	Moderate	50.52	7.88	15300.94	25.61
4	4.249-13.355	High	4.61	0.72	4059.05	6.79
5	13.356-41.489	Very high	0.37	0.06	1022.83	1.71
	Total		641.00	100.00	59751.41	100.00

Figure 5 showed the spatial distribution of erosion hotspot area and it revealed that the potential soil loss was greater along the steep slope areas. In downstream parts of the watershed over cultivation has been practiced without implementing any soil and water conservation measures which leads to the major soil erosion risks.

Generally, removal of vegetation cover through deforestation, cultivation of steep slope, overgrazing, ploughing the land several times, the practice of removing plant residues, poor physical soil and water conservation measures can cause for high soil loss in the study areas (Demeke and Andualem, 2018).

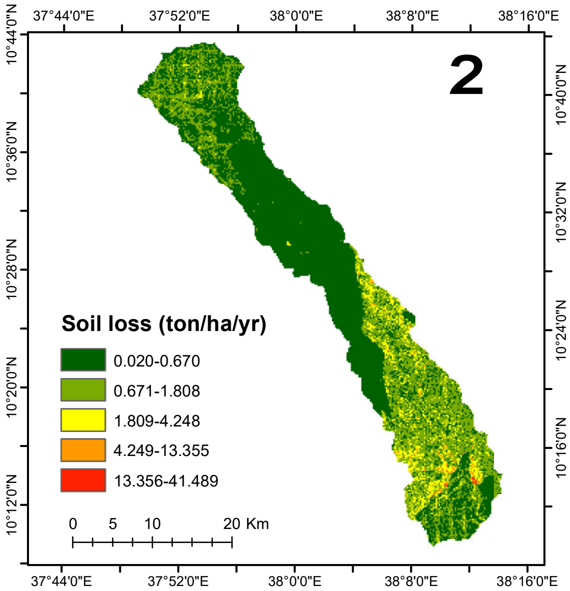

Figure 5. Soil loss rate distribution map of Muga watershed

3.3 Soil Erosion Cross Tabulation Results

Table 11 Relationship between soil erosivity and slope

Erosivity area (km^2)	Slope (degree)				
	0 – 6.91	6.92 – 13.54	13.55 – 22.19	22.2 – 34.29	34.3 – 73.5
Very low	139.93	129.85	65.90	26.11	5.51
Low	80.75	57.23	33.60	27.25	13.37
Moderate	18.45	18.05	8.50	2.82	2.22
High	0.74	1.51	1.21	0.67	0.44
Very high	0.00	0.03	0.03	0.17	0.10

The cross tabulation results between soil erosivity and slope of the area revealed (table 11) that high and very high erosive areas found in steep slopes, while most very low erosive areas were located in flat slope areas.

Table 12 Relationship between soil erosivity and major soils

Erosivity area (km^2)	Major Soil type			
	Chromic Luvisol	Eutric Vertisol	Humic Nitosol	Rendzic Leptosol
Very low	120.00	213.66	6.38	27.82
Low	59.61	112.78	17.14	22.85
Moderate	2.18	31.05	9.01	7.83
High	0.00	2.25	0.50	1.81
Very high	0.00	0.00	0.00	0.34

As showed in table 12, very high and high erosive areas were detected in Rendzic leptosols which are highly sensitive to soil erosion. On the otherhand, very low and low soil erosive areas found in chromic luvisol and eutric vertisols.

Table 13 Relationship between soil erosivity and land cover class

Erosivity area (km^2)	Land cover			
	Moderately Cultivated	Afro Alpine	Dominantely Cultivated	Urban
Very low	240.91	87.14	39.79	0.03
Low	22.38	59.61	130.22	0.17
Moderate	2.86	2.18	44.56	0.47
High	0.00	0.00	4.40	0.17
Very high	0.00	0.00	0.34	0.00

Dominately cultivated areas were detected as very high erosive areas; while afro alpine and moderately cultivated areas found very low and low erosive areas (table 13).

4. Conclusions

Using RUSLE parameters by GIS and Remote sensing techniques guarantee the handling of spatially variable data and inaccessible area easily and efficiently. The findings of this study incorporates spatially distributed soil loss rate of Muga watershed. The annual soil loss of the watershed extends from 0.02 to 41.789 t/ha/year. Very high soil loss was observed in the lower parts of the watershed at a rate exceeding the tolerable soil loss limit. This was due to the steepness of the slope and low management practices /absence of supporting the practice. This sever soil loss area could threaten agricultural productivity and extends its offsite effect of sedimentation on Abay River. In this study, slope length and gradient (LS) factor was the primary influential RUSLE parameter followed by Support Practice (P) Factor.

Substantial investment on soil and water conservation measure could be done in the lower part of the watershed irrespective of the watershed logic (conservation measures should be started at the upper part of the watershed). RUSLE does not consider gully erosion which is now seriously dissected and fragments grazing and farmlands. Thus, further study on gully erosion estimation and sedimentation is recommended.

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Data Availability
The data used to support the findings of this study are included with the article.

Conflict of Interest
The authors declare that there are no conflicts of interest regarding the publication of this paper.

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